[ENG11]

UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

B.ENG (HONS) ELECTRICAL & ELECTRONIC ENGINEERING

EXAMINATION SEMESTER 1 – 2022/2023

ELECTRICAL MACHINES & POWER ELECTRONIC DRIVES

MODULE NO: EEE6011

Date: Monday 9th January 2023 Time: 14:00 – 16:30

INSTRUCTIONS TO CANDIDATES:

There are SIX questions.

Answer ANY FOUR questions.

All questions carry equal marks.

Marks for parts of questions are shown in brackets.

Electronic calculators may be used provided that data and program storage memory is cleared prior to the examination.

CANDIDATES REQUIRE:

Formula Sheet (attached after questions).

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Question 1

a) Prove mathematically that the phasor sum of a three-phase flux space vector of 3-phase transformer is equal always to zero. **[6 marks]**

b) Figure **Q1b** shows an iron core of a magnetic circuit composed of three limbs, the left limb has a coil of N_1-turns, and a middle limb with cross section S_2 and a N_2-turn coil. The third limb on the right has an air gap of length l_4 . Left limb, right limb, the upper and lower parts of the core have all cross section equal to S_1. The data of the magnetic circuit are as follows:

$$\boldsymbol{l_{11} + l_{12} + l_{13} = 45\ cm\ , l_4 = 0.1\ cm\ , S_1 = 150\ cm^2\ , l_2 = 15\ cm\ ,}$$

$$\boldsymbol{l_{51} + l_{52} = 22.45\ cm\ ,\ S_2 = 250\ cm^2\ , l_{31} + l_{32} = 22.45\ cm\ , N_1 = 200\ , N_2 = 150}$$

Determine the current I_2 that leads to a 0.5 T magnetic induction in the air gap, assuming **I_1 =2 A** and a relative permeability of the iron core $\boldsymbol{\mu_r = 5000}$. **[8 marks]**

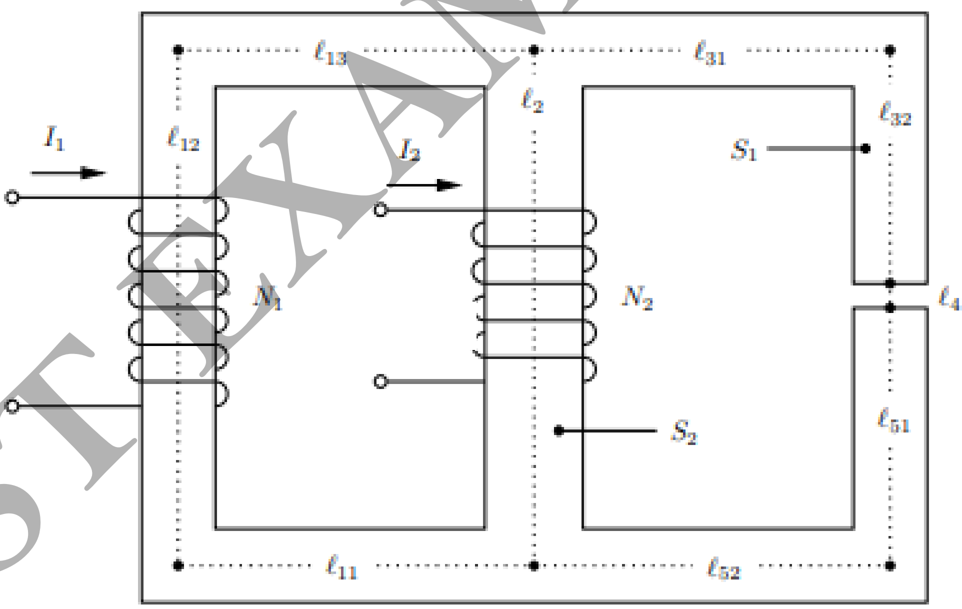

Figure Q1b

Question 1 continues over the page…

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...Question 1 continued

c) A 50 kVA, 2400:240 V, 50 Hz single-phase transformer has the following winding impedances in Ohms:

High Voltage side: 0.72+j0.92 , Low Voltage side: 0.007+j0.009

Magnetising admittance: (0.324-j2.24) X10^{-2} Mho referred to low voltage side

i. Draw the exact equivalent circuit referring all its parameters to high voltage side. **[4 marks]**
ii. Calculate the voltage regulation and efficiency when the transformer is working at 70% of its full load at 0.8 power factor lagging. **[7 marks]**

Total 25 marks

Question 2

a) What are the three factors that voltage in any real DC machine depends on? **[5 marks]**

b) A 10-pole simple lap wound generator is rated at 110 V, 600 A, and 750 rpm. It has a winding resistance of 7.2 milli Ohm and wound in 163 slots with 4 coil sides/slot and 2 turns/coil. Assume a brush voltage drop of 1.5 V. Find:

i. Rated load power **[2 marks]**
ii. Resistance, EMF, and terminal voltage per coil and per turn **[14 marks]**
iii. The developed torque and flux per pole **[4 marks]**

Total 25 marks

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Question 3

a) Enumerate five methods of the speed control of a 3-phase induction motor. **[5 marks]**

b) A 50 kW, 440 V, 50 Hz, six-pole 3-phase induction motor has a slip of 6% when operating at full load conditions. At full load conditions, the friction and windage losses are 300 W, and the core losses are 600 W. Find the following values for full load conditions:

(i) The shaft speed and rotor frequency **[3 marks]**
(ii) The load torque in Newton-meters **[4 marks]**
(iii) The induced torque in Newton-meters **[6 marks]**
(iv) The input power in watts if stator copper loss is 250 W **[4 marks]**
(v) The motor efficiency. **[3 marks]**

Total 25 marks

Question 4

a) Draw the equivalent circuit of a synchronous generator indicating all parameters. Define each parameter of the circuit and draw the voltage-current phasor diagram for leading power factor load. Comment on the relationship between the terminal voltage and the internal generated voltage. **[8 marks]**

b) A 3-phase, 8-pol, 50 Hz, 6600 V, star-connected synchronous motor has a synchronous impedance of 0.66 +j 6.6 Ohms per phase. When excited to give a generated emf of 4500 V per phase, it takes an input of 2500 kW. Calculate:

i. The electromagnetic torque **[4 marks]**
ii. The input current and power factor **[4 marks]**
iii. The load angle **[4 marks]**
iv. If the motor was to operate at an input current of 180 A at unity power factor, what would then be the value of the internal generated voltage under these calculations **[5 marks]**

Total 25 marks

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Question 5

a) Explain why the slip of the backward rotating magnetic field of a single phase induction motor equals to (2- s_f) where s_f is the slip of the forward rotating magnetic field. **[6 marks]**

b) A ¼ hp, single-phase, 120 V, 60 Hz, 2-pole induction motor has the following circuit parameters per phase referred to the stator:

$$R_1 = 2\ \Omega,\ R_2' = 4.1\Omega,\ X_1 = 2.5\Omega,\ X_2' = 2.2\Omega\ ,\ X_m = 51\Omega$$

The core losses are 30 W, the friction, windage, and stray losses are 15 W. The motor is operating at the rated voltage and frequency with its starting circuit open. For a slip of 5% determine:

(i)	The shaft speed in rpm;	**[1 mark]**
(ii)	The forward and backward impedances of the motor;	**[6 marks]**
(iii)	The input current and power factor;	**[3 marks]**
(iv)	The input, total air-gap, developed, and output powers;	**[6 marks]**
(v)	The developed torque and motor efficiency.	**[3 marks]**

Total 25 marks

Question 6

(a) Explain with drawings how a separately excited DC motor speed can be controlled by changing the magnetic field and using power electronic drives.

[12 marks]

(b) Explain with drawings how the speed of a 3-phase induction motor can be controlled by changing the voltage and frequency at the same time using power electronic drives. **[13 marks]**

Total 25 marks

END OF QUESTIONS

Formula sheet follows over the page

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FORMULA SHEETS

These equations are given to save short-term memorisation of details of derived equations and are given without any explanation or definition of symbols; the student is expected to know the meanings and usage.
DC Machines

$E=V+I_A.R_A$ (Generator voltage equation)

$E=V-I_A.R_A$ (Motor voltage equation)

$K_e=K_t=(2pCN/a)$, $E=K_e.\omega.\Phi$, $T=K_t.I_A.\Phi$

$P_{conv}=E.I_A=\omega.T$

Transformers and Induction motors

Transformer voltage ratio: $\frac{E_1}{E_2}=\frac{N_1}{N_2}$

Secondary parameters referred to primary side: $R_2'=(\frac{N_1}{N_2})^2R_2$, $X_2'=(\frac{N_1}{N_2})^2X_2$,

$I_2'=\frac{N_2}{N_1}I_2$, $V_2'=\frac{N_1}{N_2}V_2$, $P=\sqrt{3}V_LI_L\cos\theta$, $Q=\sqrt{3}V_LI_L\sin\theta$

$slip\ s=\frac{n_s-n_r}{n_s}$, $\boxed{P_{AG}=3I_2^2\frac{R_2}{s}}$, $\boxed{P_{conv}=3I_2^2R_2\left(\frac{1-s}{s}\right)}$, $\boxed{P_{core}=3E_1^2G_C}$,

$\tau_{ind}=\frac{(1-s)P_{AG}}{(1-s)\omega_{sync}}$

$\boxed{\tau_{ind}=\frac{P_{AG}}{\omega_{sync}}}$

Synchronous machines (For motor the above equations will be used in the reversed order)

Voltage vector equation: E =V + I.Z

Power equations: P= $\frac{EV}{Z}\cos(\psi-\delta)-\frac{V^2}{Z}\cos(\psi)$, Q= $\frac{EV}{Z}\sin(\psi-\delta)-\frac{V^2}{Z}\sin(\psi)$

For generator

$$P_{in}=\tau_{app}\omega_m\ ,\ P_{conv}=\tau_{ind}\omega_m=3E_AI_A\cos\gamma\ ,\ P_{out}=\sqrt{3}\,V_L\ I_L\cos\theta$$

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